

Local Grid Refinement

Introduction

Simulations of groundwater flow and transport often need highly refined grids in local areas of interest to improve simulation accuracy. For example, refined grids may be needed in

- regions where hydraulic gradients change substantially over short distances, as would be common near pumping or injecting wells, rivers, drains, and focused recharge;
- regions of site-scale contamination within a regional aquifer where simulations of plume movement are of interest; and,
- regions requiring detailed representation of heterogeneity, as may be required to simulate faults, lithologic displacements caused by faulting, fractures, thin lenses, pinch outs of geologic units, and so on.

Refinement of the finite-difference grid used by MODFLOW can be achieved using several methods; the advantages and disadvantages of each are explained below.

Globally Refined Grid

In this case, the grid is refined over the entire domain.

Advantages:

- Easy to build the grid
- Can yield reliable results
- No limitations for contaminant transport or particle tracking simulations

Disadvantages:

- Creates a needless amount of grid cells outside the area of interest, resulting in longer simulation times.

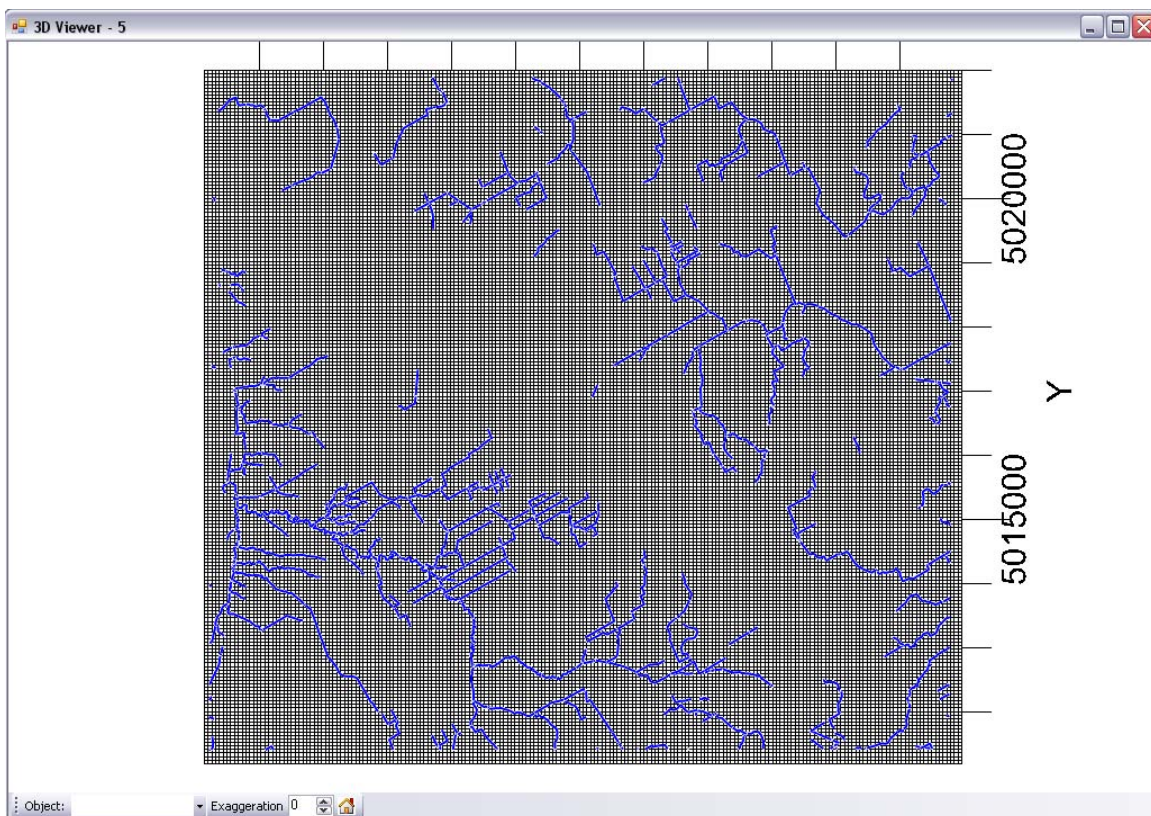


Figure1: Globally refined numerical grid, in Visual MODFLOW 3D-Builder

Variably-Spaced Grid

Using a variably spaced grid, the grid spacing is small around the area of interest, and gradually increases in size away from this area, out to the boundary of the model domain. Also referred to as Gradational Mesh Refinement (GMR), this is the most commonly used method.

Advantages:

- Ideal method for some cases
- A regular structure between adjacent cells
- A single model that is solved in a single (iterative) matrix equation; and hence “real-time” feedback between the coarse and fine grid areas through this single matrix solution.
- Ideal for contaminant transport and particle tracking simulations

Disadvantages:

- Not ideal if refinement is needed in multiple areas of the domain (for example, a number of well fields scattered throughout the study area) as it can result in a fine grid over the entire domain)
- Creates a needless amount of grid cells outside the area of interest, resulting in longer simulation times
- Can result in cells with large aspect ratios at the boundary of the domain, which can lead to numerical errors
- Working with these grids (construction, data input, and post-processing) is more arduous than with uniformly spaced grids.
- No vertical refinement (of a localized area)

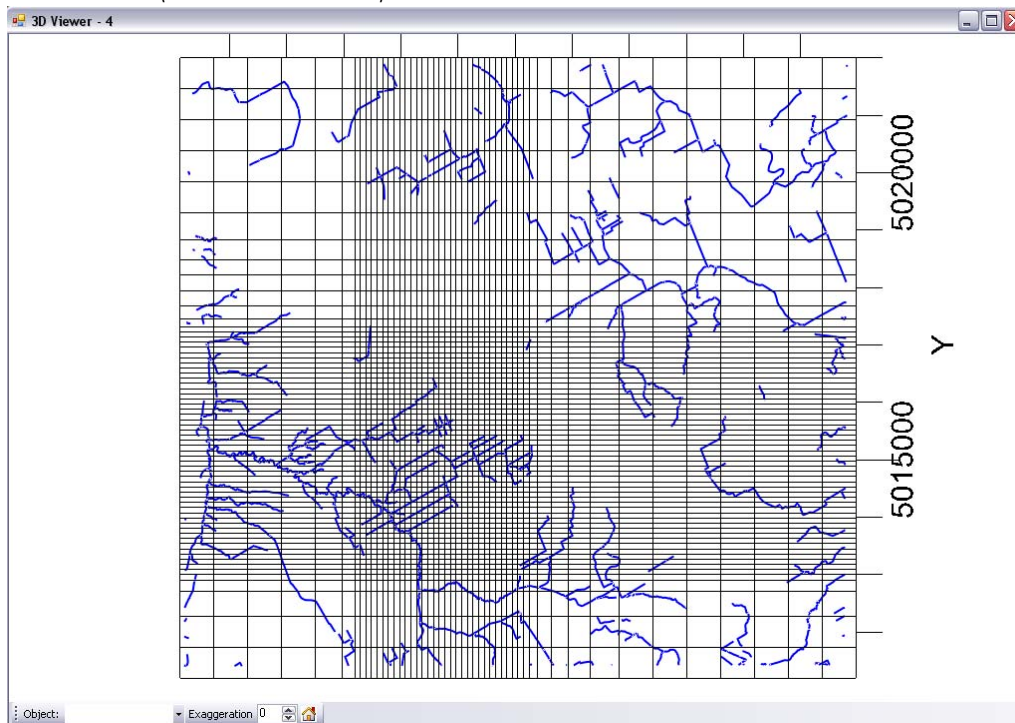


Figure2: Numerical grid with refinement around area of interest

Telescopic Mesh Refinement (TMR)

The TMR (telescopic mesh refinement (TMR) approach combines two or more different-sized finite-difference grids—usually a coarse grid, which incorporates regional boundary conditions, and a locally refined grid, which focuses on the area of interest. The link between the coarse and local grids is most commonly accomplished by first simulating the coarse grid and using its results to interpolate heads and fluxes, or a combination of both, onto the boundaries of the local grid.

Advantages:

- Straightforward, flexible, and easy
- Works well for some (but not all) problems
- Computationally efficient

Disadvantages:

- No vertical refinement (of a localized area, that differs from the background grid)
- No support for contaminant transport or particle tracking simulations across the local-child grid interface.
- This approach is one-way coupling only (from the coarse grid to the local grid) and does not allow for feedback from the local grid to the coarse grid. Therefore, after running both models, the burden is placed on the modeler to check if heads along and fluxes across the interfacing boundary are consistent for both models. If they do not match, there is no formal mechanism for adjusting the models to achieve better agreement

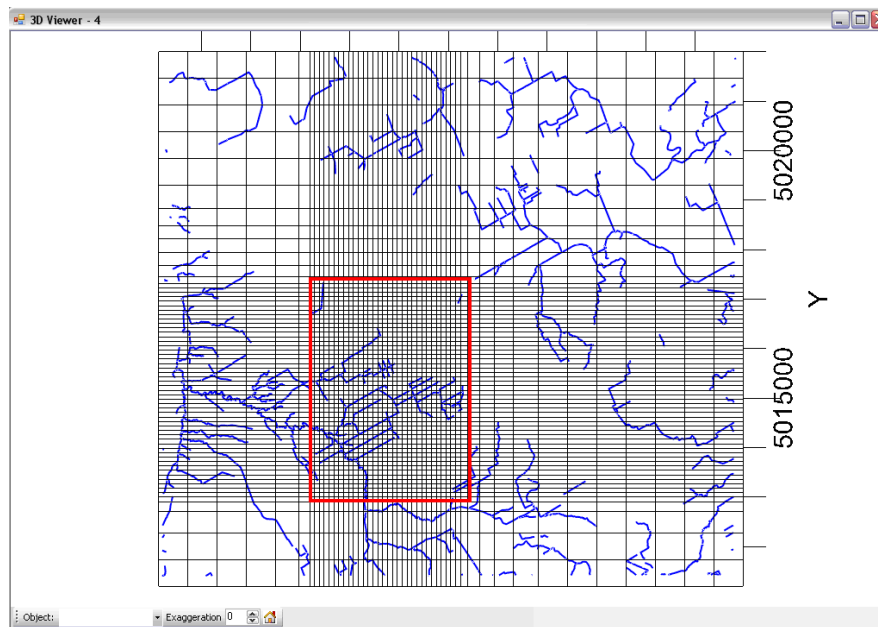


Figure 3: Coarse and fine grid. NOTE: The figure above is a demonstration only; TMR is not supported in Visual MODFLOW3D-Builder

Local Grid Refinement (LGR)

This method, links two or more different-sized finite-difference grids: a coarse (parent) grid covering a large area which incorporates regional boundary conditions, and a fine (child) grid covering a smaller area of interest. The grid refinement covers only the area of interest. In Visual MODFLOW 3D-Builder, the implementation is based on MODFLOW 2005-LGR.

Advantages:

- Create cells only in the area of interest, therefore less computationally intensive
- Support for refinement in multiple areas (create up to 9 child grids)
- Define a vertical refinement in the child grid that is different from the parent grid
- Two-way feedback between the coarse and local grids, ensures that the models have consistent boundary conditions along their adjoining interface.
- Easy to design the child grids
- Offers immediate results

Disadvantages:

- No support for contaminant transport or particle tracking simulations across the local-child grid interface. (However, the parent and child models can be run separately in this cases, using the generated BFH (Boundary Flow and Head) package files.

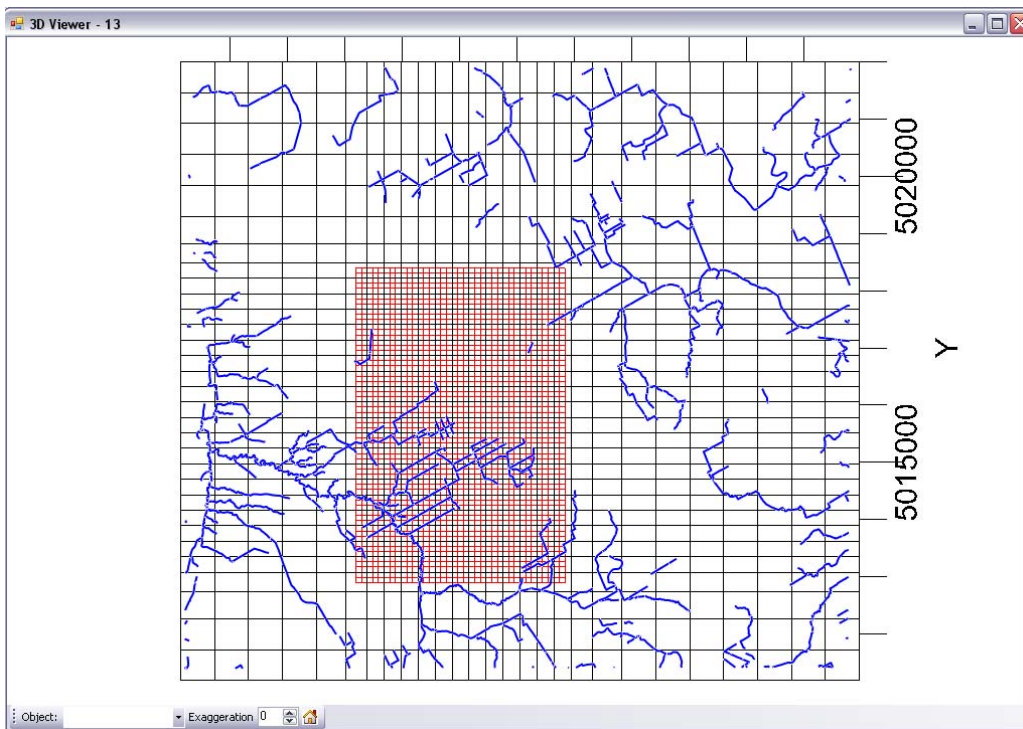


Figure 4: 2D Viewer showing parent grid (grey gridlines) and child grid (red grid lines) in Visual MODFLOW 3D-Builder

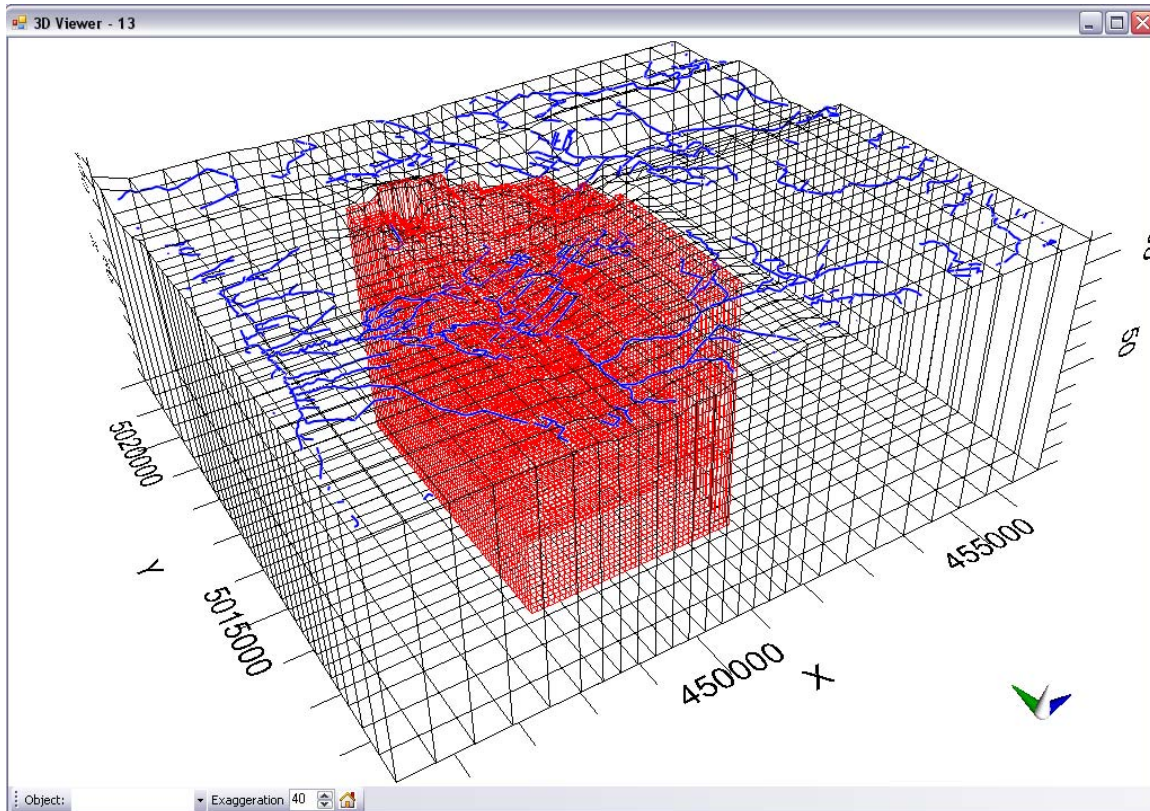
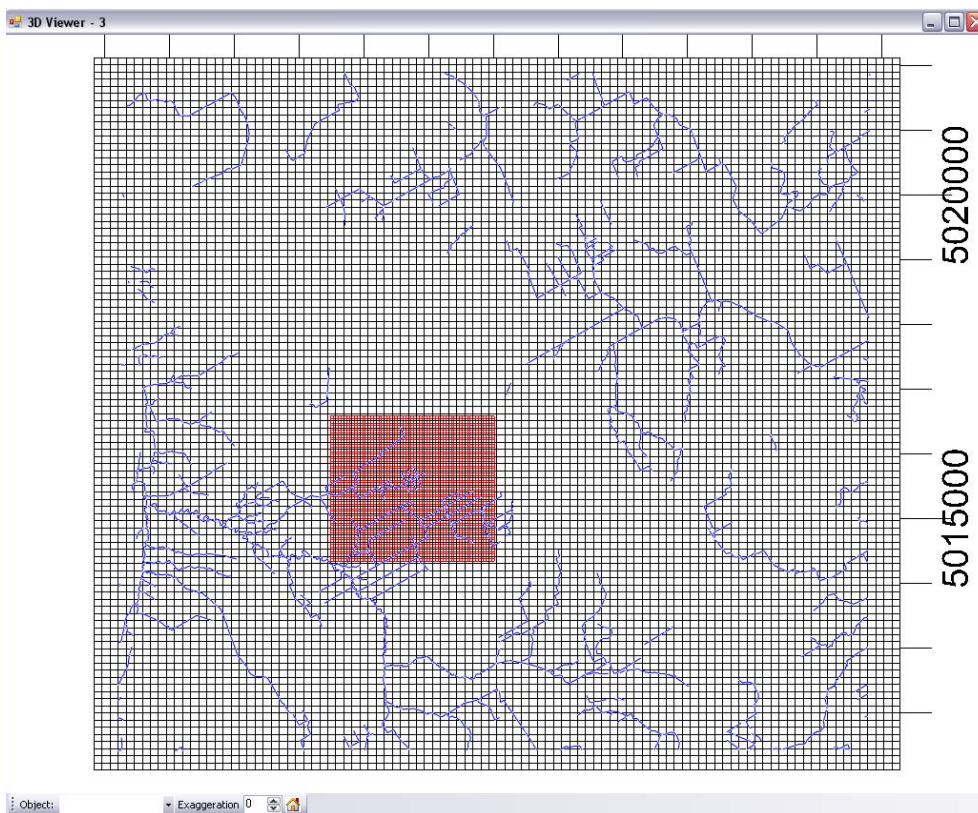


Figure 5: 3D View showing parent grid and child grid

Example

In the example below, a regional-sized conceptual model was created for an area covering 10 km X 10km (approx. 40 square miles). A uniform grid of 100 rows * 100 columns, covering the entire conceptual model area, was generated. A child grid was generated around the area of interest, covering an area of 20 rows and 20 columns, using a horizontal grid refinement ratio of 3:1; this resulted in a child grid with a grid size of 60 rows * 60 columns. There was no vertical refinement done on the child grid. The child grid is shown below colored in red.



River boundary conditions were defined for the regional model, using a polyline shapefile that was imported; these are displayed above in blue. The parameters for the rivers can be defined manually, or mapped to attributes in the shapefile, (or using a DEM for calculating river stage).

The conceptual model, and the parent and child grid, are ready for translation. The Translation wizard can be launched as shown below; select MODFLOW-2005-LGR as the simulator, and select the appropriate numerical grid, which contains the child grid.

Translate to Numerical Model

Define Simulation Settings

Settings

Output name
C:\NumericalModels\sample\Example_CHILD1.NAM

Translation Log file
C:\NumericalModels\sample\Example_CHILD1.LOG

Simulator
MODFLOW-2005-LGR

Property Package
LPF

☐ Translate as MODFLOW parameters

Numerical Grid
NumericalGrid3

☐ Use Local Grid

Simulation Type
Steady-State Flow

Start Date
8/25/2008

Start Time
12:00:00 AM

Steady-State Simulation Time [s]
1

Translation Format
MODFLOW format

Select Packages to Translate

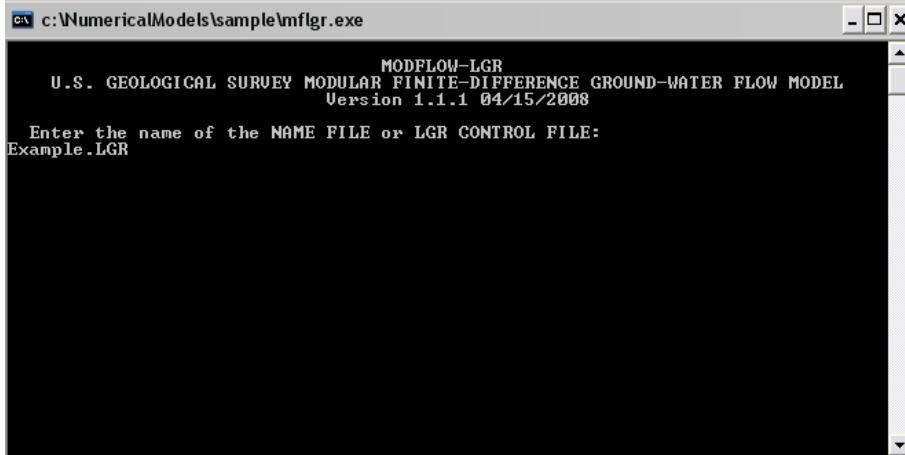
- ☒ LPF
- ☒ BAS6
- ☒ DIS

Previous Next >> Cancel

After you complete the translation, the following files will be generated:

- MODFLOW files for the Parent Grid (Example_PARENT.NAM, Example_PARENT.LPF, Example_PARENT.BAS, Example_PARENT.DIS, Example_PARENT.RIV, etc.
- MODFLOW files for each of the Child Grid(s) (Example_CHILD1.BAS, Example_CHILD1.DIS, Example_CHILD1.LPF, Example_CHILD1.NAM, Example_CHILD1.RIV)
- Example.LGR - this is the Control File, that contains details on the linkages between the parent and child grid(s)
- The Boundary Flow and Head (BFH) Package file, which allows the child and parent models to be simulated independently using the boundary conditions obtained through the iterative process of LGR.

To run the simulation with the MODFLOW2005-LGR, launch mflgr.exe, and enter the name of the .LGR file (For example, mflgr.exe).



The MODFLOW2005-LGR engine will start, then generate result files (.LST, .HDS, etc.). The volumetric budget in the LST should contain an entry for the Parent Flux boundary condition (an example from the Parent model is below).

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 1 IN STRESS PERIOD 1			

CUMULATIVE VOLUMES	L**3	RATES FOR THIS TIME STEP	L**3/T

IN:		IN:	
---		---	
STORAGE =	0.0000	STORAGE =	0.0000
CONSTANT HEAD =	158.2277	CONSTANT HEAD =	158.2277
RIVER LEAKAGE =	142.0706	RIVER LEAKAGE =	142.0706
PARENT FLUX B.C. =	51.2186	PARENT FLUX B.C. =	51.2186
TOTAL IN =	351.5168	TOTAL IN =	351.5168
OUT:		OUT:	
----		----	
STORAGE =	0.0000	STORAGE =	0.0000
CONSTANT HEAD =	154.0517	CONSTANT HEAD =	154.0517
RIVER LEAKAGE =	22.3512	RIVER LEAKAGE =	22.3512
PARENT FLUX B.C. =	175.5873	PARENT FLUX B.C. =	175.5873
TOTAL OUT =	351.9903	TOTAL OUT =	351.9903
IN - OUT =	-0.4734	IN - OUT =	-0.4734
PERCENT DISCREPANCY =	-0.13	PERCENT DISCREPANCY =	-0.13

The calculated .HDS file can be loaded into Visual MODFLOW 3D-Builder, for further interpretation and analysis.

Conclusions

The various methods of grid refinement all have advantages and disadvantages. The appropriate method selected should be based on your project objectives and application. Using Visual MODFLOW 3D-Builder, it is possible to design globally refined grids and variably spaced grids for simulation with MODFLOW 2000,2005. Local grids can be generated for simulation with MODFLOW 2005-LGR.

References

Steffen Mehl, Mary C. Hill. MODFLOW-2005, THE U.S. GEOLOGICAL SURVEY MODULAR GROUND-WATER MODEL – DOCUMENTATION OF SHARED NODE LOCAL GRID REFINEMENT (LGR) AND THE BOUNDARY FLOW AND HEAD (BFH) PACKAGE. U.S. Geological Survey Office of Ground Water and U.S. Department of Energy, 2005.

Steffen Mehl, Mary C. Hill, and Stanley A. Leake . Comparison of Local Grid Refinement Methods for MODFLOW. GROUND WATER 44, no. 6: 792–796, 2006

Matthew Tonkin, Marinko Karanovic, Andrew Hughes, Christopher Jackson. New and Contrasting Approaches to Local Grid Refinement, MODFLOW and More 2006: Managing Ground-Water Systems - Conference Proceedings. 2006